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Listed Alphabetically by First Author

Recurrence of Highstands of Great Salt Lake, Utah

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Great Salt Lake is the largest closed-basin lake in the western hemisphere. Great Salt Lake and the Great Salt Lake Desert have a drainage basin of about 23,000 square miles that a covers portions of four states and is affected by more than one weather system. The lake has risen 10 feet above its historical average elevation twice in the last 150 years, flooding 750 square miles of low-lying land in and adjacent to Wasatch Front communities. The first rise crested in the early 1870s, about 25 years after the Mormon pioneers had settled near the shore of the lake. The 1870s highstand was not measured at that time, but later measurements of the shoreline formed by the 1870s highstand indicate that the stillwater lake elevation was 7212 feet above sea level. Weather records for the drainage basin during this period are fragmentary but suggest that the lake rose in response to a 4- or 5-year wet cycle. In the mid-1870s, the lake began a general decline that lasted until 1963, when the lake reached its historical low level of 4191 feet above sea level. Consumptive use of water in the drainage basin contributed to the lake's decline, but its importance was overestimated and led most planners and developers to conclude that the lake would never rise again to its 1870s flood levels.

From 1963 to 1982, the lake rose about 10 feet to near its historical average. A 4-year wet cycle began over the drainage basin of the Great Salt Lake in 1982. The lake rose dramatically and crested in 1986 and 1987 with an elevation of the main body of the lake equal to that of the 1870s highstand. The 1980s flooding of Great Salt Lake disrupted lifelines and industries on the lake and cost public and private entities hundreds of millions of dollars.

Defining the flood hazard associated with expected highstands of Great Salt Lake requires knowledge of the morphology of the lake bed to define at what elevations the lake will tend to stabilize plus knowledge of weather patterns, wind durations, and velocities to determine flooding from lake set-up and wave run-up.

Also needed, and lacking, is an understanding of the recurrence of the various highstand elevations that should be expected. The historical record is too short to determine recurrence. Prehistoric lake level fluctuations can be studied by shorelines, lagoonal deposits, and other features formed during highstands and by sediment cores. Decision-makers want to know: (1) how to tell when a 4- to 6-year wet cycle has begun, (2) the expected highstand elevation that has a recurrence interval on the order of 100 years — an event that should be of concern to major construction on the lakebed, and (3) the expected highstand elevation that has a recurrent interval on the order of several hundred years. Highstands with recurrence intervals on the order of thousands of years are not considered useful for most planning purposes.

The Near-1600 AD Multi-Proxy Puzzle

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A newly-developed chronology of annual varve thickness (AD 1117-1992) from the Santa Barbara Basin has been decomposed into orthogonal components using singular spectrum analysis (SSA) to identify and retrieve interdecadal oscillations. SSA eigenfunctions (EOFs) 1-8 form four oscillatory pairs with periods of ~100, ~58, ~25, and ~12 years respectively, all of them above the noise floor and in strong quadrature, with the possible exception of EOFs 7-8. Based on 2500 simulated series and on two-sided confidence intervals, EOFs 1-7 are significant at the 99% level and EOFs 8-9 are significant at the 95% level; EOFs 8-9 are significant at the 95% level using a one-sided test. The deterministic oscillatory signals retrieved from the marine varves show an abrupt change in frequency and amplitude near AD 1600. The largest contribution to this environmental shift is given by the interdecadal components, especially the ~25 and the ~12-year oscillation, suggesting a connection with global-scale decadal cycles identified in the subtropical Pacific gyre circulation and, possibly, with solar-driven phenomena. the near-1600 AD event coincides with (a) a similarly sudden change of state in the nearby Santa Monica Basin that triggered the onset of laminations in the marine sediments, (b) an extreme drought over most of the American Southwest. Total organic carbon burial flux in Santa Barbara Basin varves also shows a marked change around AD 1600 and seems highly correlated with detrended varve thickness. It is now our purpose to investigate further the time series properties of geochemical parameters derived from Santa Barbara Basin varves and to refine our understanding of the physical mechanisms that link oceanic circulation and atmospheric processes in the Eastern Pacific on decadal to centennial timescales.

Salmon Migration and Extreme Climatic Events at Various Scales

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Strong associations between the nearshore migration of two groups of British Columbia salmon and environmental variables are discussed. Both cases have considerable biological, commercial, and biopolitical importance. In these associations, the responses vary continuously over a wide range of oceanographic data. The salmon appear to control the temporal but not the spatial scale nor the intensity of the response.

In one case, Fraser River sockeye seem to spatially adjust their final southward migration route to move inside Vancouver Island in a negative response to offshore SSTs, if the latter are above about 15°C. However, if the SST anomaly occurs too close to shore, the response of the salmon is more complex and they may be delayed and/or forced to travel west of the island at unusual depths.

In the second example, southern British Columbia coho salmon that spawn in the fall in rivers in Georgia Strait (east of Vancouver Island) are found in their final summer inside or outside the strait. In years in which salinity of the strait

in the previous winter/spring has been low, a small fraction are caught inside. The nature of this association is a mystery and bears no obvious relationship to the timing of the major physical and biological changes in the strait and in the coho salmon.

The Effects of Climate and Man on the Bering Sea Ecosystem: Developing a Context

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The Bering Sea is one of the most productive marine ecosystems on the planet. Despite a variety of recent protections for marine mammals, birds, and fish resources, some species of the Bering Sea and adjacent regions have undergone large and sometimes sudden population fluctuations. As part of an NRC study to assess the current scientific understanding of the Bering Sea, a new view of how sequential change occurs in marine ecosystems has begun to develop. One thing is clear, most ecosystem issues arise in response to no single cause. In the case of the Bering Sea, climate forcing along with some long-term effects of exploitation by man appear to have led to current conditions. The scenario developed by the NRC committee presents a very different view of cause and effect than that normally employed in fishery management organization.

Historic 1000-Year Storms of California

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This is a study of 46 California storm events where the return period was 1000 years or more, based mainly on an analysis of daily rainfall records. The period of time covered in this study is from the major flood of 1862 up to 1995. This study describes a dataset compiled originally for drainage engineering studies. The basic data of this study consist of tabulated daily rainfall records from 3000 California rainfall records. Depth duration frequency studies were prepared for each record. The record length averaged 35 years of data for each station. The statistically smoothing procedure is discussed. Maps of lines of equal return period were prepared for each storm event with a 1000-year return period. The storm events with high return periods were distributed in a random pattern over the entire state. Five hundred and forty daily rainfalls in excess of 10 inches in one day were shown to be distributed on the windward slopes of orographic barriers. It was concluded that one million dollars in damage resulted from each rainfall station reporting the highest ever rainfall during a storm.

The Global Paleoflood Database Project

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In certain environments, excessive flood events have left behind datable century-to-millennium-aged geomorphic indicators of their occurrence and magnitude on the landscape. These paleorecords of large floods provide us with one of the best indicators of the occurrence of past hydrologic extremes, as well as indirect

evidence of the extreme rainfall events that generated the floods. The Global Paleoflood Database project has been initiated to compile various types of paleoflood information and incorporate it into a flexible-but-structured database that will allow regional and global analyses and comparisons.

The objectives of the GDP are: (1) to compile a global database of existing paleoflood information and establish a central repository for future submissions of paleoflood data; (2) to supplement the paleoflood data with complementary information from the gaged record; (3) to assemble a bibliographical database of paleoflood literature cross-referenced with the databases; (4) to establish an Internet and World Wide Web forum for communication among paleoflood researchers; and (5) to identify areas where future collection and analysis should be directed to adequately represent paleoflood extremes in climatically-sensitive regions of the world. The ultimate goal of the project is to provide a repository and communication forum to facilitate and stimulate research about climate variability and hydrological extremes through the accelerated sharing of paleoflood information. As this repository evolves, it will serve as a platform for examining the long-term patterns, processes, and causes of extreme streamflow and precipitation events throughout the world.

Radiocarbon Record of Abrupt Oceanographic Changes in the Santa Barbara Basin Over the Past 20,000 Years

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Radiocarbon dating by accelerator mass spectrometry of coexisting planktonic and benthic foraminifers separated from Santa Barbara Basin sediments were used to provide a chronology for the upper 70 meters of core from Ocean Drilling program Hole 893A. The ^{14}C chronology allows a determination of the age of the Younger Dryas (YD) in Santa Barbara Basin, and provides evidence for changes in ocean circulation in the eastern Pacific over the past 20,000 years. The YD event is represented in the Santa Barbara Basin by a climatic change based on oxygen isotopic shifts measured in planktonic and benthic foraminifers, and occurs in a non-laminated interval within laminated sediments at a depth of 17.60 to 20.40 mbsf. The event was dated using six planktonic foraminifer samples. The calibrated radiocarbon age for the initiation of the YD in Santa Barbara Basin is 12,970 year BP, coincident with that in North Atlantic deep-sea cores, glacial deposits in New Zealand, and ice core records. The radiocarbon age for the termination of the YD in the Santa Barbara Basin is poorly constrained due to a 1300-year radiocarbon plateau, falling between 11,000 and 12,300years before the present. Assuming a constant sedimentation rate in the core, the termination age would be 11,220 years BP, with a duration of 1750 years. During the YD, the planktonic-benthic age difference averaged 90 years, compared with an average value of 470 years in younger and older sediments. The age decrease of surface-to-bottom waters during the YD may reflect a change in source of Pacific Intermediate Water, with a greater proportion originating from a more proximal source.

Climatic Impacts on Terrestrial Vegetation as Deduced from Leads and Lags in Atmospheric Carbon Dioxide and Temperature Signals

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Observations of atmospheric CO_2 suggest that climatic variability affects the global carbon cycle on all time scales that can be explored using existing records. We will discuss interannual variations on time scales longer than El Niño events which appear to reflect imbalances between the uptake and release of CO_2 by vegetation and soils, the former expressed as net primary production (NPP), and the latter by heterotrophic respiration (HR). Both the seasonally-adjusted concentration of atmospheric CO_2 and the amplitude of its seasonal cycle are affected by these imbalances. The annual average difference in NPP and HR causes interannual variations in the seasonally-adjusted concentration while variation in the annual sum causes variations in the amplitude of the seasonal cycle (the latter relationship, because the drawdown phase of the seasonal cycle depends mainly on NPP, the return phase on HR). The phase relationship between interannual signals in amplitude and concentration should, therefore, be related to how variations in NPP and HR have affected both signals. We have found that quasi-decadal variations in the amplitude of the seasonal cycle in atmospheric CO_2 lag similar variations in the seasonally-adjusted concentration by about 2 years. We have also found that quasi-decadal variations in air temperature are nearly in phase with these variations in atmospheric CO_2 as we have reported previously as PACLIM meetings. It follows that NPP and HR on the decadal time scale were in balance at times of nearly simultaneous quasi-decadal maxima and minima in CO_2 and temperature, while a quarter of the decadal cycle (about 2 years) after a decadal maximum, NPP maximally-exceeded HR; and about 2 years after a decadal minimum, HR similarly exceeded NPP. Because the observed quasi-decadal amplitude signal, as described above, also has lagged temperature by about 2 years, decadal maxima in amplitudes have evidently occurred approximately when NPP has maximally exceeded HR, and vice versa. We suggest that changes in the length of the growing season of plants at higher latitudes may account for these relationships.

Modeling and Predicting Intertidal Variations of the San Francisco Bay Salinity Field

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An intertidal model of current velocities and salinity distributions in the San Francisco Bay estuary (Uncles and Peterson, 1995) is introduced and shown to reproduce available Bay salinity observations on daily to interannual time scales with reasonable accuracy. The UP model is distinguished by its coarse resolution and its use of tidally-averaged physics, which enable it to simulate variations in the baywide salinity field on a longer timescale than was previously feasible.

A simulation of the salinity distribution from 1930 through 1990 provides a historical context for an examination of the Bay's response to unusually wet and

dry water years. The behavior of the North Bay is shown to be relatively straightforward, responding quickly to changes in Delta outflow: high flows produce low salinity and vice-versa. The modeled South Bay response is more subtle, with dependence on the outflow's recent history as well as concurrent local and Delta flows.

A calibration of model parameters with respect to observed salinities yields a more realistic simulation throughout the Bay and provides further insight into Bay dynamics. Salinities landward of Carquinez Strait are shown to be highly sensitive to mixing processes in the strait and San Pablo Bay. Calibration results also indicate that estuarine circulation in this region may be considerably stronger than theory suggests.

The UP model's economic computational requirements and baywide domain offer the prospect of using the it as a forecasting tool. To this end, a predictive scheme is explored wherein a freshwater inflow prediction is developed from winter/spring runoff and snowpack. The predicted runoff serves as input to the estuarine model, providing ESP-type salinity estimates days and months in advance. The model's forecast capabilities show particular promise in dry years such as 1994, when low inflows allow tidal mixing to dominate the dynamics, and the UP model's dynamical accuracy yields an effective salinity prediction. In wetter years such as 1995, the salinity is more dependent on the hydrological details, but the model still permits an accurate prediction of the year-end salinity rise.

Preliminary Evidence Linking Regional Climate Variability to a Recent and Dramatic Collapse of the Mexican Sardine Fishery

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The Gulf of California has been the most important region for the Mexican pelagic fishery since the mid 1970s, mainly because of the Monterey sardine landings. From 1976/1977 the catch increased from 25,000-30,000 t to a maximum of 290,000 t in 1988/1989. However, in the next two seasons the fishery collapsed to less than 120,000 t in 1988/1989 and 7,500 t in 1993/1994. After this event, the catch recovered to 100,000 t in 1993/1994 season. The fact that the effort level did not change markedly during the 1984-1991 period, strongly suggests that these variations were caused mainly by environmental factors. The Gulf of California sardine population inhabits the region near the large Islands of the Central Gulf given that there exist high productivity and low temperature conditions through the year. During winter the sardine expands its distribution in order to spawn over the Sonora-Sinaloa coastal seasonal upwelling region. Considering that an optimal set of environmental conditions for the spawning has been suggested for other sardine populations around the world, we analyzed the spawning extension as a function of both a local wind derived upwelling index and sea surface temperature. We found that the period in which the fishery increased is related to low levels of upwelling activity as well as to a sustained decrease in sea surface temperatures. Further, the onset of the collapse corresponded to the highest level of upwelling activity since the beginning of the fishery. It is suggested that reproductive success, and so next year's population biomass, partially depends on the sardine's habitat availability of an

adequate set of environmental conditions; identified here as a combination of optimal levels of both temperature and upwelling activity.

Potential Global Terrestrial Carbon Sink is 2.5 Times "Missing Sink"

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I have recently developed a global terrestrial carbon sequestration model which uses two driving parameters to bound terrestrial carbon sink associated with an increase in atmospheric CO_2 concentration (C_0). The first parameter is a leaf-level function (L), the normalized photosynthetic response to a small change in C_a, which has been found to be an invariant function of C_0, independent of almost all biological and environmental factors. The invariance of L enables us to cut across spatial heterogeneity of biotic and abiotic variables to quantify the Ca-induced increment of global photosynthetic carbon influx (P_G). The second parameter is the global mean residence time (τ_G) of photosynthetically-fixed carbon, which is used to project global respiration (R_G), that is the return of carbon to the atmosphere through biology, from P_G. If τG is, for example, 10 years, this year's R_G is approximately equal to PG 10 years ago. This year's PG, on the other hand, is that of 10 years ago plus the increment caused by the C0 increase during the past 10 years. That increment can be quantified by and is the potential carbon sink in global terrestrial ecosystems. This model estimates that τG is 17.7 years and the global carbon sink is 5.0 GtC yr-1, approximately 2.5 times "missing sink."

The Regional Response of Salmon Populations to Climate Variability in the Northeast Pacific

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As part of the Integrated Assessment of the Dynamics of Climate Variability, Impacts, and Policy Response Strategies in the Pacific Northwest project, we have examined relationships between historical climate indices and salmon production in the northeast Pacific. The primary goal of our study is to identify the regional and species-specific responses of Pacific salmon to large-scale climate forcing. We have separated the salmon production records into 10 geographical regions: Western, Central, and Southeast Alaska; Northern, Exterior, and Interior British Columbia; Washington Coast, Puget Sound, Oregon; and California.

Statistical analysis techniques were applied to identify the coherent salmon population responses to climate variability. Our preliminary results demonstrate that when salmon production is high in Alaska, it tends to be high in Puget Sound and low in California and Oregon. The opposite-signed relationships are also evident.

Salmon production in the British Columbia and Washington Coast regions tend to have less obvious connections to large-scale climate indices than those in Alaska, Puget Sound, California, and Oregon. Interestingly, salmon production in Puget Sound is well correlated with that in Alaska and poorly correlated with

that in neighboring regions. We also find that linkages to the El Niño/Southern Oscillation are most evident at the latitudinal extremes of our salmon production regions, in the sense that warm (cold) ENSO years are generally poor (good) salmon production years in California and Oregon and good (poor) salmon production years in Alaska. We offer some possible mechanisms by which these relationships may be driven.

A Decadal Change in the North Pacific Thermocline and Gyre-Scale Circulation

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A cooling of the thermocline at 250-400m depth from the early 1970s to the early 1980s in the North Pacific Ocean is identified in observations and in a numerical simulation. The observed change in the thermocline has gyre scale and is intensified in the western part of the basin north of 20°N. In an ocean model, forced by observed wind stress and heat flux anomalies from 1970-1988, a similar change in thermocline structure occurs. The model current fields reveal that the North Pacific subpolar gyre strengthened by about 10/% from the early 1970s to the early 1980s in the sense that the Kuroshio/Oyashio extension and the subpolar gyre return flow were increased. The model thermocline cooling and concomitant circulation changes were driven by a decadal-scale change in basin-scale wind stress curl forcing (Ekman pumping) with the response being nearly in Sverdrup balance over much of the eastern half of the basin.

Synoptic Climatology of Beringia Since the Last Glacial Maximum

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Beringia, comprised of Alaska and eastern Siberia, generally north of 60°N, provides unique opportunity for understanding past climatic variations since around 18 ka. Numerous new proxy data sites have been added to the paleoclimatic data network over the past several years, particularly fossil pollen and lake-level evidence. The output of paleoclimatic simulations from several different versions of general circulation models and unexploited modern climatic data are also available. This study examines the synoptic paleoclimatology of Beringia by comparing results from both GCMs and proxy data with one another, augmented by using information from modern synoptic climatology. Although boundary conditions since the late Pleistocene obviously differ dramatically when compared to today, some aspects of atmospheric circulation from the modern record provide an understanding of the synoptic climatic controls that predominated in the past. Results suggest that synoptic climatic features, such as the East Asian trough, the Siberian high, and the pacific subtropical high, may explain some spatially heterogeneous paleoclimatic patterns as suggested by proxy data, including differences in the vegetation histories between western and eastern Beringia.

The Large-Scale Context for Recent Precipitation Extremes in Western North America

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Extreme events in regional-scale precipitation may be explained, to a large extent, by basin or hemispheric-scale variations of the climate system. I have examined these variations during several recent periods of unusual precipitation in western North America. My focus was on periods of high precipitation, lasting one to several weeks (for example, the heavy rains in Arizona during early 1993, in California during early 1995, and in the Pacific Northwest during late 1995). Preliminary analyses suggest that many of these precipitation extremes were part of larger-scale disturbances with origins in several distant upwind areas. The most important of these disturbances were intraseasonal variations in: (1) tropical cyclone activity in the eastern Indian Ocean and western Pacific; (2) cold surge activity in eastern Asia; and (3) El Niño and La Niña processes in the tropical Pacific. There are also indications that sea surfaces temperature anomalies in the nearby northeastern Pacific may have contributed to the precipitation extremes induced by these larger-scale disturbances.

Fisheries Catastrophes in Slow Motion: Wind Stress and Sustainable Development

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Analyses of the variations of the Japanese and California sardine and mackerel fisheries and the North American albacore fishery suggest that the principal time scale of the population variability of these stocks is decadal or regime scale. productive periods have lasted up to two decades and have occurred at intervals of 40 to 60 years. Climatic analyses of the CEOS's version of the COADS dataset clearly demonstrate regime-scale climatic variations in sea surface temperature, atmospheric pressure patterns, and wind indices which are proxies for turbulent mixing, Ekman transport, and wind stress curl.

Major climatic changes appear to be primarily associated with basinwide, regime-scale variation in the intensity and position of the winter atmospheric pressure patterns in the North Pacific. this basin-scale variation in wind stress, in association with regional scale features, results in greatly altered air/sea interactions which control the oceanic circulation. Areas particularly affected by the regime-scale variation include the Oyashio-Kuroshio mixing area east of northern Honshu, the Kuroshio extension region, and the northern California Current to Gulf of Alaska region.

There is evidence that population declines of major stocks of North Pacific pelagic fishes are associated with regime changes which alter the productivity of feeding grounds of these stocks. the failure of fisheries management regimes to reduce exploitation rates to compensate for the decreased productivity has led to fishery collapses with resultant long-term reductions in fishery yields.

Seasonal Streamflow Forecasting in Australia Using the Southern Oscillation Index

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Previous studies have shown that climate variability in Australian is strongly linked to the El Niño/Southern Oscillation (ENSO). Extreme droughts in Australia occur when the Southern Oscillation Index is strongly negative. In this study, the potential of using the SOI to forecast seasonal streamflow in eastern Australia is investigated. A probabilistic streamflow forecast is made from an optimal linear combination of climatology, persistence, SOI Phase, and Linear Discriminant Analysis forecasts. This is referred to as a consensus model approach and is used by the Australian Bureau of Meteorology to make seasonal probabilistic forecast of precipitation.

The climatology forecast is based on the natural probabilities of receiving below normal (30%), normal (40%), or above normal conditions (30%). The persistence forecast uses the previous 3-month average streamflow value to make a probabilistic forecast of the next seasons streamflow. The influence of ENSO in the generation of streamflow is accounted for in the SOI Phase and LDA forecast models. The SOI Phase model uses the strength and trend in the previous months SOI to forecast the next season's streamflow, and the LDA model evaluates the shift in the SOI during below normal, normal, and above normal streamflow conditions. The optimal linear combination of the four models is the forecast that minimizes the mean square error (Half-Brier score) and is the forecast with the best skill.

This modeling approach is used on 10 unimpaired streamflow stations from eastern Australia for the period 1927-1992. In general, the persistence model is most useful in the austral winter (July-September). The SOI phase and LDA models also provide valuable information in the winter. During years of high (positive) SOI values, there is a high probably of receiving normal or above normal streamflow. Conversely, there is a high probably of receiving below normal streamflow when the SOI is strongly negative. Preliminary results suggest that this approach may give water resource planners and managers valuable information for the design and allocation of water supplies.

ENSO Connections to Western Canada, the U.S. And Mexico

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Previous studies have shown that ENSO has significant associations with the winter climate of the western United States. The status of ENSO is portrayed, for this purpose, by the Tahiti minus Darwin Southern Oscillation Index. Maximal correlation occurs at a lag of about 4 months (SOI leading climate). Positive summer/autumn SOI is followed by wet and cool winters in the Pacific Northwest, and dry and warm winters in the Desert Southwest. Negative summer/autumn SOI is followed by the opposite pattern. A gridded precipitation dataset (Mike Hulme, Climatic Research Unit, East Anglia) is used to extend these analyses to western Canada, southern Alaska and northwest Mexico. The relationship

earlier seen for the southwest U.S. extends well into Mexico, and the opposing relationship seen in the Pacific Northwest extends well into western Canada. The latter relationship is nearly centered on the Columbia River Basin, whose runoff shows the same relationship. Relationships for both centers of action, as measured by correlation and split sample techniques, are strongly significant. The relationship noted over the Columbia River Basin gives way to an opposing, but weaker, relationship along the Pacific Coast from the Queen Charlotte Islands northward toward Yakutat and westward toward Kodiak Island. Although relationships derived from gridded values do not pass significance tests in this region, those derived from some individual station data do. These surface-based results are consistent with results of upper air analyses. In the Desert Southwest, extreme events (number of days exceeding selected thresholds of rain or snow) are also significantly related to the phase of ENSO.

The Top Ten California Floods of the 20th Century

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This paper is a review of the 10 biggest floods during this century in northern and central California, starting with the 1970 flood which was the pattern for design of the Sacramento River Flood Central Project, and ending with the 1995 floods. There are regional differences in exposure to storm-bearing winds which affect the extent of precipitation in a given area. The most feared general floods are those caused by a slow-moving weather system with a long southwestern fetch over the ocean, extending from Hawaii. Although heavy rains are usually widespread in these flood events, the brunt of the storm will be concentrated in different areas. For example, the December 1964 storm hit the north coast region hardest, while the February 1986 storm was worst in a broad band from the north San Francisco Bay through the north central Sierra. Orographic lifting is a strong factor in heavy rain production. Snow levels during a storm are another factor. Snowmelt floods are only a problem in the southern Sierra.

Southern California's "Flood of the Millennium" Occurred Ca. 1605 AD: Historical and Multi-Proxy Evidence for Large-Scale Atmospheric Forcing

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A distinct 1- to 2-cm thick flood deposit found in the Santa Barbara Basin with a varve-date of AD 1605±5 years testifies to an intensity of precipitation that remains unmatched for later periods when historic or instrumental records can be compared against the varve record. The 1605±5 event correlates well with Enzel's finding of a Silver Lake playa perennial lake at the terminus of the Mojave River (14C-dated AD 1560±90; Enzel 1992, The Holocene 2:11-18), in relative proximity to the rainfall catchment area draining into the Santa Barbara Basin. According to Enzel, such a persistent flooding of Silver Lake playa occurred only once during the last 3,500 years and required a sequence of floods, each comparable in magnitude to the largest floods in the modern record. To gain confidence in dating of the 1605±5 event, we compare Southern California's sedimentary evidence against historical reports and multi-proxy time-series that

indicate unusual events or are sensitive to changes in atmospheric circulation patterns. To name a few, tree-rings near Santa Barbara recorded very high precipitation for 1604, on top of a high 11-year average for 1601 to 1611 (Haston and Michaelsen 1994, Journal of Climate 7:1373-1387). Devastating drought conditions during the 1590s in Mexico City changed in 1604 and 1607 to such severe flooding that a drainage canal was excavated out through the northern part of the basin (O'Hara and Metcalfe 1995, The Holocene 5:485-490). Between 1599 and 1608, northern Italy experienced its densest cluster of severe and great winters in recorded history (since 1406; Camuffo and Enzi 1992, in: Climate Since A.D. 1500, p. 143-154). Overall, the first decade of the 17th century was marked by a rapid cooling of the Northern Hemisphere, with some indications for global coverage. A very large 1601 volcanic eruption recorded in Greenland Crête ice core acidity (Hammer et al. 1980, Nature 288:230-235) and 1604 marking a 270-year minimum of D14C (Stuiver and Braziunas 1993, The Holocene 3:289-305) seem to be linked to the observations, although no consensus has been reached about underlying causal mechanisms. We speculate about changes in atmospheric circulation over North American that may have been responsible for climate anomalies around 1605 AD.

Interdecadal Variability in North Pacific Wind and SST

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From an analysis of historical observations over the last half century, areas of the North Pacific (e.g., California-Alaska Currents, Kurishio-Oyashio Currents) exhibit clear regional variability on decadal time scales. Fisheries and other biological components also fluctuate on similar time scales, suggesting a coupling between climate variability and ecosystem structure (population size and range, feeding patterns, species composition). In the California Current, for example, SST has warmed and equatorward wind stress has increased south of Monterey. However, the region north of Monterey features a cooling tendency that coincides with increasing equatorward stress off northern California and increasing poleward stress off the Pacific Northwest. Cross-shelf differences in SST and wind are noted as well, particularly off the northwestern United States.

No clear systemwide relationship between SST and local coastal wind is seen in the California Current on interannual and longer scales. We examine the large-scale seasonal fluctuations in the wind field and its derivatives (e.g., wind curl, wind mixing) over the North Pacific in the decades prior to and following the 1976 climate shift, as a possible forcing mechanism for West Coast temperature variability. A complex interaction of spatially as well as temporally varying Ekman advection, wind mixing, and direct heating appears to be responsible for the long-term fluctuations in SST in the northeast Pacific.

The wintertime intensification of the Aleutian Low produced anomalous eastward wind stress south of 40°N and rotated stress in the Gulf of Alaska to the northwest. The resulting anomalous (1976-85 relative to 1966-75) winter Ekman surface flow was divergent (upwelling favorable) over the central North Pacific, but convergent off the western North American and eastern Asian coasts. Regions of anomalous surface divergence (convergence) are strongly correlated with anomalously cool (warm) SST in winter. Summer wind and SST anomalies

are not spatially correlated. SST winter anomalies appear to propagate in a manner consistent with the large-scale ocean circulation, resulting in a summer distribution of SST anomalies that is determined from late-fall and winter atmospheric anomalies. One example is the cool anomaly off the Pacific Northwest, which appears to be advected into the region from the central North Pacific via the West Wind Drift.

Increasing Evidence of Severe, Persistent, and Widespread Drought in the Western United States During Medieval Time

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Evidence from an increasing number of sites in the western United States indicates that severe and persistent drought characterized much of the region during upper Medieval times. At previously described localities in the central Sierra Nevada, water levels in lakes, rivers, and marshes dropped lower than at any time during the past 150 years, permitting trees to colonize the emergent lands. Ring counts and radiocarbon dates from relict stumps of these trees point to two desiccation events — AD ~900-1120, and ~1200-1350 [Stine, Nature, v. 369, 546-549 (1994)]. Similar evidence, of identical antiquity, has now been found in the northern Sierra at Independence Lake [Lindstrom, J. Ca. and Gr. Bsn. Anth., v. 12, 146-157 (1990)]; east of the sierra at Walker Lake; and in the southern Sierra at Owens Lake, where rooted shrub stumps and artifacts of the "Rose Spring" type litter the artificially exposed playa. Drought in the Sierra at these times is corroborated by the dendroclimatic record [Graumlich, Quat. Ros., v. 39, 249-255 (1993)] [D. Graybill, pers. com., 1991)].

In the northern Rocky Mountains, D. Love (pers. com. 1996) reports drowned tree trunks, with a death date of ~AD 1350, rooted on the floor of Jenny Lake in the Tetons; and L. Hadley (pers. com., 1996) described contemporaneous evidence of desiccation-induced vegetation change from packrat middens in Yellowstone. Still father east, in the sands of Nebraska and eastern Colorado, dunes that had been anchored for thousands of years lost their vegetation and became mobile during upper Medieval time, burying soils and damming the South Platte River [Madole, Geol., v. 22, 483-485] [J. Swinehart, pers. com. 1995]. These new records contribute to a lengthening list of sites from the Americas (southern and northern Andes, Yucatan, central Mexico) and beyond, that point to a marked Medieval Climatic Anomaly.

A Detailed 2,000-Year Late Holocene Pollen Record from the Lower Pahranagat Lake, Southern Nevada, USA

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Analysis of 266 pollen samples from the upper two-thirds of a 15-m long, 10-cm diameter set of overlapping cores retrieved from Lower Pahranagat Lake (elevation 975 m), Lincoln County, Nevada, gives us a rare, continuous, record of vegetation change at an interval of every 14 years over the last 3.8 ka. Each sample averaging ~3.8 years of pollen with ~10.4-year gaps between each sample outlines a record of alternating dry and wet periods with rapid onsets and

terminations. During this period increasing Piñus (pine) pollen values with respect to Juniperus (juniper) pollen values indicate that pinyon pine is now more abundant in the southern Great Basin than at any time since the beginning of the "Neoglacial" ~4.0 ka. This is due not only to a shift from harsher winters about 2.0 k, in part evidenced by the decline of juniper dominance in the woodland, but also to an increase in summer shifted rainfall which has favored seedling survival during the summer.

Additional evidence of periods of summer shifted rainfall is seen in the expansion of grasses (reflected in Poaceae pollen) preceding expansions of piñon pine without coincident expansions of winter rainfall-loving species such as sagebrush and juniper. Expansion of piñon at this time is also indicated in pollen records from the Carson Sink of the north-central Great Basin (Lead Lake, NV) and of grasses in pollen records from the northern Great Basin, e.g., Diamond Pond, Nevada. Periodic increases in the values of sagebrush (Artemisia) pollen, sometimes coincident with increases in juniper pollen, reflect intervals of cooler climate. Occasional, sometimes severe, drought is marked by increased bur sage (Ambrosia-type) and saltbush (Chenopodiineae) pollen and decreased regional conifer pollen. Drier climate between 3.0 and 2.5 ka, 2.4 and 2.0 ka are eclipsed by the severe droughts of the last 2 ka. In particular, the droughts between 1.9 and 1.6 ka and 0.9 and 0.3 ka have little parallel during the late Holocene in southern Nevada. The ratio of aquatic to littoral pollen types indicates generally deeper water conditions ~1.6 to 1.3 ka and more variable, but predominately more marshy, conditions during most of the last 1.3 ka. Accompanying geomorphic investigations suggest that the sudden shift from lake to marsh conditions may be linked to the impact of extreme rainfall events that eroded a spillway through the alluvial fans that impound the lake during the early portion of the Late Holocene.

Daily Rainfall Along the U.S. Pacific Coast Appears to Conform to a Square-Root-Normal Probability Distribution

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Daily rainfall data from 24 Pacific coastal stations, from San Diego to Cape Flattery with >40 year records, were examined during a study of the influence of regional climatic variations on rainfall thresholds for initiating landslides. Statistical analysis of the data disclosed an unexpected result — the square root of the daily rainfall closely approximates a normal distribution function. In fact, while the fit-to-daily rainfall data provided by the conventional log-normal distribution is fair, r^2 = 0.83 to 0.90, the fit from a square-root normal distribution is significantly better, r^2 = 0.98 to 0.999. This greater precision enables meaningful, quantitative comparisons of rainfall records from gages in different locations, and provides a sharper tool for delineating both spatial and temporal variations in precipitation. Several examples of the use of the square-root-normal distribution to explore variations in precipitation along the U.S. Pacific Coast will be discussed, including such effects as orographic enhancement, rain shadows, and the increase in storm frequency with geographic latitude.

Poster Presentations

Butte Valley, California: A Pollen and Paleomagnetic Record for the Past 3 MA

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A 102 m core recovered by the U.S. Geological Survey from Butte Valley, Siskiyou County, California, has yielded long records of paleomagnetic and pollen data. Initial interpretation of the record was based on an assumption of uniform sedimentation rates based on the position of the Brunhes/Matuyama boundary at 65 m depth, and produced an estimated age for the base of the section of 1 MA. More detailed analyses have led us to reject this model in favor of a new model in which sedimentation rates were much slower prior to the Brunhes/Matuyama boundary; this new model makes much better sense in terms of the paleomagnetic reverse record observed below 65 m in the core. Our new estimate of the age of the base of the Butte Valley core is about 3 MA, making the Butte Valley core span about the same time interval as the Tule Lake core, about 50 km to the east.

The lithology of the Butte Valley core indicates that the valley has become less lacustrine through time; lake sediments comprise a larger fraction of the section toward the base of the core than toward the top. We attribute this tendency to a drop in the regional water table caused by the incision of the Klamath Gorge just to the north of Butte Valley.

Comparison of the Butte Valley and Tule Lake pollen records indicate generally similar vegetation development in the two basins, but with some differences as a result of the position of Butte Valley closer to the Cascade Range than Tule Lake is. The slow sedimentation rate in the lower part of the Butte Valley core has resulted in rather long intervals between sample points in the lower part of the section.

Geomorphic Evidence for an Extreme Climate Episode in the American Southwest (Young Dryas)

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Eolian and shoreline landforms in the Estancia Basin in central New Mexico were generated and shaped during the large and abrupt changes in climate that occurred at the glacial termination and during the younger Dryas (YD) climatic episode. Gypsum dunes which were generated from sediments on the desiccated floor of the lake basin, after ~11,000 radiocarbons BP, were reshaped into a prominent beach ridge after a lake returned and quickly rose ~10 meters above the lake floor, to an elevation of 1862 meters. A minimum age for the gypsum beach ridge is 9650 radiocarbons BP, as determined by radiocarbon dating of shell material in channel-fill sediments within deltaic deposits at the same shoreline elevation. The age window for the beach ridge corresponds approximately to the radiocarbon age plateau associated with the YD event. the YD lake was sustained at the 1862 m elevation or some unknown interval of time, after which

the lake abruptly fell in elevation and disappeared. The rise and fall of the lake had a minimal effect on the dune field, with significant reworking restricted to the downwind, eastern side of the lake, where dunes were reorganized into linear shoreline features. Within the dune field, the dunes have largely retained their complex dune forms, including barchan shapes, indicating that the lake rose and fell rapidly, having little time to reshape dune forms within the gypsum dune field. The preservation of fragile eolian landforms, under conditions where their survival is unexpected, is consistent with evidence from other regions for extremely abrupt changes in climate during the YD climate episode.

Long-Term Response Of Torrey Pine (Southern California) to Coastal Climate: Precipitation, Temperature, and Fog

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Torrey pine (Pinus torreyana Parry ex Carr.) has one of the most limited geographical ranges and population size in the Pinus genus; it is present only on Santa Rosa Island and on the coast between San Diego and Del Mar, where our research was conducted. A 168-year chronology (1827-1994) was developed using 28 increment cores extracted from 15 living and 2 dead standing trees at Torrey Pines State Reserve, San Diego, California. Crossdating was possible but not easy, mostly because of faint latewood boundaries in certain years and specimens. Annual tree growth was highly and directly related to precipitation falling between the previous November and the current April. Temperature was not a significant predictor of tree growth. At seasonal scale, tree growth was highly and directly related to winter and spring precipitation, and was also significantly correlated to summer fog. However, when combined with winter and spring precipitation in multiple regression models, summer fog was not a significant predictor of tree growth. Total November-April precipitation explained a larger amount of variance after 1900 (64% in 1900-1949, 70% in 1950-1994) than before 1900 (48% in 1850-1899). The spatial correlation with western North America winter and spring precipitation, as well as with published tree-ring chronologies, indicates a connection with the American Southwest. Global correlation maps with winter sea level pressure and sea surface temperature are consistent with the hypothesis that San Diego precipitation is affected by a southerly displaced North Pacific storm track and by warmer water farther south, both leading to higher transport of lower latitude moisture.

Correlation of Paleoclimate Records from Upper Klamath Lake and from the Continental Margin Off California

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A 12.8 m piston core from Upper Klamath Lake, Oregon contains a high-resolution paleoclimate record of the past 40 kyr based on diatoms, geochemistry, pollen, and sediment magnetic properties. Age controls are provided by radiocarbon dating and tephrochronology. Abrupt fluctuations in abundances of planktic diatoms with different seasonal adaptations between 35 and 19 ka suggest alternating warm and cold climate regimes. The warm intervals correspond to eutrophic lake

conditions. The fluctuations in diatom abundance correspond to fluctuations in the input of glacial flour, inferred from magnetic and geochemical properties. Full glacial diatom assemblages are dominated by reworked Pliocene species and taxa that today bloom under the ice in north-temperate oligotrophic lakes. During the full glacial, magnetic properties indicate maximum flux of glacially-derived sediment. Post-glacial climates after 13 ka produced a seasonally shallower, eutrophic lake that gave way to encroaching marshes by 8 ka. Marsh development with anoxic sediments reached a maximum between 7 and 5 ka, with sediment organic-carbon concentrations as high as 48 weight percent.

Marine cores collected from within the oxygen minimum zone on the continental slope off northern and central California contain intervals of laminated sediments between intervals of bioturbated sediment in sections deposited between about 50 and 25 ka (i.e. during oxygen-isotope stage 3). Enhanced preservation of organic matter and elevated concentrations of molybdenum in the laminated sediments suggest that bottom waters were severely oxygen-depleted and perhaps anoxic when these sediments were deposited. The organic-rich, laminated sediments further imply that the California current system was more productive at that time. The laminated sediments, and peaks in percent organic carbon and molybdenum, may correspond to peaks in abundance of eutrophic diatoms in the core from Upper Klamath Lake, but there is not as yet sufficient age control for the marine cores to confirm this correlation. In contrast to the inferred high organic productivity on the California margin during oxygen-isotope stage 3, marine full-glacial organic productivity was the lowest of anytime during the past 50 kyr. The climate and hydrology of the western U.S. is controlled by seasonal interactions of the North Pacific high, the Aleutian Low, and the western U.S. Low. These major atmospheric circulation systems control the California current upwelling system as well as the location and intensity of storm tracks bringing precipitation to the western U.S.

Decadal Variability of Snow in the Western U.S.

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Much of the water supply in the western United States is derived from snowmelt runoff. For example, it is estimated that 75% of the annual discharge of most of the major streams in the western U.S. is from melting mountain snowpack (Palmer 1988). Topography plays a strong role — the heaviest snow accumulations are at middle-to-high elevation mountain sites, usually with exposures to the west or southwest. In the Sierra Nevada, the primary water-bearing region for California, most snowmelt is derived from snowpack accumulated during winter storms at elevations above 1300 meters. Regional precipitation is very seasonal; most locations west of the Rocky Mountains have a winter maximum and a summer minimum. Combined with the annual temperature cycle, this seasonality produces a spring maximum in snow accumulation, so that most snowcourses attain their climatological maximum snow water equivalent (SWE) at about the beginning of April. Snowcourse observations are generally collected on or about the first of the month during the winter and spring. The greatest frequency of sampling over the historical period is for April 1.

How much variability occurs in the snow accumulation? A survey of historical snowcourse records over the western states indicates the coefficient of variation (CV) of April 1 SWE ranges from 20% to well over 100%. For the 200 snowcourses used in this study, 45 had a CV >50%, while only 23 had a CV <25%. This level of variability is comparable to that of seasonal precipitation over this region (Granger 1977; Chanagnon et al 1991). Snowpack accumulations are coherent over scales of at least a few hundred kilometers; Aguado (1990) showed in California that for 28 snowcourses across the Sierra Nevada Mountains, over 80% of the variance of SWE was accounted for by a single principal component.

Although mountain snow accumulations have been routinely monitored for several years to gauge water supplies, these measurements have not been fully exploited as a climate dataset. A comprehensive study of short period climate variability of snowpack in the West has not been undertaken, but there are noteworthy regional examples. In examining snowcourse records in the Rocky Mountains, Changnon et al (1991) demonstrated that spring snow accumulation serves as a regional climatic indicator; Changnon et al (1993) derived effects of synoptic atmospheric circulation patterns and a tendency for out-of-phase multi-year shifts in snow accumulation and associated circulation patterns over the central part of the northern and southern Rocky Mountains. Concerning El Niño, Redmond and Koch (1991) demonstrated that snowfall in Oregon is significantly biased, with a low in years with a low SOI (Southern Oscillation Index) relative to those with a high SOI; and Cayan and Webb (1992) derived the pattern of SWE over the western United States in conjunction with the SOI.

Both precipitation and temperature affect the snowpack, but their aggregate impacts are not entirely clear. There does not appear to be a strong temperature/snow relationship over the entire region (Walsh et al 1982; Leathers and Robinson 1993; Karl et al 1993). However, anomalous temperature impacts are evident in Sierra Nevada spring runoff variations (Aguado et al 1992; Cayan et al 1993). Also, winter temperature trends appear to be involved in a decades-long change in the fraction of runoff occurring in late spring and summer runoff found in the Sierra Nevada and many other snowmelt-driven streams over the western United States (Roos 1987, 1991; Wahl 1992; Aguado et al 1992; Dettinger and Cayan 1995). Its dependence on temperature makes snow a key diagnostic in climate change scenarios (eg, Gleick 1987; Roos 1989; Lettenmaier and Gan 1990; Dettinger and Jeton in press). Temperature and precipitation are not well correlated during the cool seasons in the West (Zhao and Khalil 1993; Cayan and Peterson 1993), so their individual influences on snowpack should be separable.

Issues

In view of the above, the purpose of this study is to examine a network of mountain snowcourses over the western United States to examine the following issues associated with snow accumulation. These issues include: the way in which the space/time structure of the decadal (>7-year period) variability at high elevation snow accumulation is revealed by mountain snowcourse snow water equivalent (SWE) records (1930-1989); the consistency of SWE variability when compared to other hydrological measures (eg, temperature, precipitation, and streamflow); the

relationship of SST variability to large-scale fields of atmospheric circulation and SST; and a comparison of decadal SWE variability to that of the ENSO timescale.

Data

For several decades, the U.S. Department of Agriculture Soil Conservation Service has archived snow observations (depth and water content) at several hundred mountain snowcourses in the western United States (Stafford 1959; Work and Beaumont 1959). Throughout the West, many snowcourses were established in the mid-to-late 1930s in response to the early 1930s western drought.

Snowcourses are commonly sited in sheltered alpine meadows so that drifts, blowing snow, and excessive sublimation are minimized. More recently, many automated show sensor observations are available over the western region; these records are limited to the last 10-15 years and may have errors in measuring seasonal accumulation of snow, so they are not employed in the present study. Most snowcourses are monitored at the beginning (on or about the first of the month) and sometimes the middle of each of the substantial snow-covered months, usually from January or February through May or June. Here, we use the first-of-the-month snowcourse samples because mid-month samples are generally not available over the complete record. Snowcourses cover a large range of elevation, from less than 1000 meters to over 3000 meters. Most of the lowest snowcourses are in the Oregon and Washington coastal ranges; most of the highest ones are in the southern Sierra Nevada in California or the southern Rocky Mountains.

The 200 snowcourses employed are from a network of more than 2000 snowcourses in the 11 western states of the conterminous United States (Palmer 1988; State of California 1991). Data from Alaska were not used in the present study because Alaska has relatively short records and because British Columbia sites were not available. Many snowcourses in this network are sited in very close proximity, so anomalous variability at a particular site is likely redundant with that of neighboring stations (Aguado 1990). The 200 snowcourses were selected to provide a relatively complete record (most of them span 1930-1989, and none begin later than 1940). The stations were culled to provide a relatively uniform spatial sample: the following mix of sites was included: 5 from Washington, 29 from Oregon, 21 from California, 3 from Arizona, 9 from Nevada, 25 from Utah, 32 from Idaho, 27 from Montana, 19 from Wyoming, 26 from Colorado, and 4 from New Mexico. Other studies (Aguado 1990; Changnon et al 1991) have demonstrated much regional coherence of the spring snow accumulation within networks of the snowcourses in California and the Rocky Mountain states, respectively, so results of this study are not likely to be very sensitive to this choice of stations.

Most snowcourses attain their climatological maximum snow water equivalent at about the beginning of April. Snowcourse observations are generally collected on or about the first of the month during the winter and spring; the April 1 sampling tends to be the period with the greatest frequency of sampling over the historical period. However, some low elevation sites and some of the southernmost sites experience maxima as early as February 1, and some of the

high-elevation sites have maxima delayed until May. Of the 200 snowcourses used in this study, 149 had climatological maximum first-of-the-month values on April 1; 29 had maxima on March 1; 19 had maxima on May 1, and 3 had maxima on February 1.

April 1 observations are the primary data used in the present study, but observations from the other months are also used to track the seasonal evolution of the snow. April 1 is the most commonly sampled period over the duration of record, probably because maximum snow accumulation at most stations is reached in early April. the seasonal progression of snow accumulation at representative locations is shown later in the regional SWE composites. Snow depth is generally measured concurrently with SWE at each snowcourse. At the 200 snowcourses include here, April 1 snow depth and SWE are high correlated; nearly all (199) have correlation coefficients exceeding 0.8; many (160) have correlations of 0.909, and several (84) have correlations exceeding 0.95.

Atmospheric circulation is represented by Northern Hemisphere sea level pressure (SLP) from 1899 to present, obtained from NCAR and the NOAA Climate Analysis Center. The SLP data are monthly averages over a 10° longitude by 5° latitude "diamond grid" since December 1946.

SST is from the GISST adjusted and filled global anomaly set (Parker and Jackson) from about 1900 to present. In addition, we have augmented the SST with a set of gridded land temperatures obtained from Henry Diaz and Jon Eischied (NOAA, Boulder, CO).

Streamflow is from a set of about 60 USGS stream gauge records, as described in Cayan and Webb (1992).

Conclusions

A major portion (about 55%) of the decadal SWE variability is expressed in two EOFs; a northwest pattern (Washington, Oregon, Idaho, Montana, and western Wyoming); and a southwest/northwest opposition pattern (California, Nevada, Utah, and southwestern Colorado out of phase with northern Idaho and Montana). The northwest pattern has had three or four major rhythms since 1930; the opposition pattern has had two broad maxima in the late 1930s to early 1940s and in the early 1980s. Interestingly, the decadal/spatial patterns of EOFs 1 and 2 have very strong resemblance to the spatial patterns of EOFs 1 and 2 of ENSO-filtered SWE.

Decadal SWE fluctuations over the western United States are produced by regional/basin-scale atmospheric circulation patterns, with major features over the North Pacific. The relationship to decadal SST anomalies produced surprisingly strong correlations with global features; in particular, the opposition pattern exhibits marked correlations with tropical SST over the Pacific and the Indian Ocean basins. Although these decadal analyses are based on a painfully short (60-year) record, there is support for a true physical mechanism in the form of analogous linkages on the ENSO time scale. The correlation pattern on the ENSO scale with SST produces a nearly identical pattern. Further, the temporal variability (PC) of the second SWE decadal EOF is quite closely coherent with that of a global precipitation mode (rooted in the Sahel, among

other regions) that is associated with global SST, as has been noted by several authors. Thus, it appears that a part of the low-frequency precipitation variability in western North America is associated with a global low-frequency climate mode.

References

Aguado, E. 1990: Elevational and latitudinal patterns of snow accumulation departures from normal in the Sierra Nevada. Theor. Appl. Climatol. 42:177-185.

Aguado, E., D. Cayan, L. Riddle, and M. Roos. 1992: Climatic fluctuations and the timing of West Coast Streamflow. J. Climate 5:1468-1483.

Cayan, D. R., and R.H. Webb. 1992. El Niño/Southern Oscillation and streamflow in the western United States. Pages 29-68 in El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation. H Diaz and V. Markgraf, editors. Cambridge Univ. Press.

Changnon, D., T.B. McKee, and N.J. Doesken. 1991: Hydroclimatic variability in the Rocky Mountains. Water Resources Bulletin 27:733-743.

Changnon, D., T.B. McKee, and N.J. Doesken. 1993: Annual snowpack patterns across the Rockies: long-term trends and associated 500 mb synoptic patterns. Monthly Weather Review 121:633-647.

Dettinger, M.D., and D.R. Cayan. 1995. Large-scale atmospheric forcing of recent trends toward early snowmelt runoff in California. J. Climate 8:606-623.

Gleick, P.H., 1987. The development and testing of a water balance model for climate impact assessment: Modeling the Sacramento Basin. Water Resources Res. 23:1049-1061.

Granger, O.E. 1977: Secular fluctuations of seasonal precipitation in lowland California. Mon. Wea. Rev. 105:386-397.

Jeton, A.E., M.D. Dettinger, and J.L. Smith. 1996. Potential Effects of Climate Change on Streamflow, Eastern and Western Slopes of the Sierra Nevada, California and Nevada. USGS Water Resources Investigations Report 95-4260. 44 pp.

Karl, T.R., P.Y. Groisman, R.W. Knight, and R.H. Heim Jr. 1993: Recent variations of snow cover and snowfall in North America and their relation to precipitation and temperature variations. J. Climate 6:1327-1344.

Leathers, D.J., and D.A. Robinson. 1993. The association between extremes in North American snow cover and United States temperatures. J. Climate 6:1345-1355.

Lettenmaier, D.P., and T.Y. Gan. 1990. Hydrologic sensitivities of the Sacramento-San Joaquin River basin, California, to global warming. Water Resources Res. 26:69-86.

Palmer, P.L. 1988: The SCS snow survey water supply forecasting program: current operations and future directions. Proceedings of Western Snow Conference, Kalispell, Montana. pp. 43-51.

Redmond, K.T., and R.W. Koch. 1991. Surface climate and streamflow variability in the western United States and their relationship to large scale circulation indices. Water Resources Research 27:2381-2399.

Roos, M. 1987. Possible changes in California snowmelt patterns. Proc. Fourth Pacific Climate Workshop, Pacific Grove, CA. 141-150.

Roos, M. 1989. Possible climate change and its impact on water supply in California. Oceans '89 Conference, Seattle, Washington.

Stafford, H.M. 1959: History of snow surveying in the West. Proceedings of the Western Snow Conference. pp. 1-12.

State of California. 1991. 1991 California Snow Survey Measurement Schedule. California Cooperative Snow Surveys, Department of Water Resources, Hydrology Branch, Sacramento. 55 pp.

Wahl, K.L. 1992. Evaluation of trends in runoff in the western United States. Managing Water Resources during Global Change. Proc. American Water Resources Association 28th Annual Conf. and Symp., Reno, NV, Amer. Water Resource Association. pp. 701-710.

Walsh, J.E., D.R. Tucek, and M.R. Peterson. 1982. Seasonal snow cover and short term climatic fluctuations over the United States. Mon. Wea. Rev. 110:1474-1485.

Work, R.A., and R.T. Beaumont. 1958. Basic data characteristics in relation to runoff forecast accuracy. Proceedings of Western Snow Conference, Bozeman, Montana. pp. 45-53.

Zhao, W., and M.A.K. Khalil. 1993. The relationship between precipitation and temperature over the contiguous United States. J. Climate 6:1232-2336.

Geochemical Characteristics of Sediments on the Peru and California Margins

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Sedimentary characteristics of Holocene muds deposited under an intense oxygen-minimum zone (OMZ) on the Peru margin were mapped by submersible and studied in surface-deployed box, gravity, and piston cores and submersible-deployed push cores on two transects over depths of 75 to 1000 meters across the Peru margin (12° and 13.5°S) on two cruises in 1982 and 1992. The organic matter on the Peru margin is almost entirely marine as confirmed by rock-Eval pyrolysis and isotopic composition of organic carbon (OC). OC and trace-metal concentrations are highest (up to 16 wt. % OC) in sediments where intermediate water masses in the core of the oxygen minimum zone (OMZ) with low dissolved oxygen concentrations (<5-10μM) impinge on the continental slope at depths of 75 to 450 m. Oxygen concentration is the primary control on organic matter preservation, but sediment transport and reworking by strong bottom currents exerts a secondary control on organic-matter preservation. High concentrations of OC and metals also were observed in inner shelf (<100 m) sediments where the sediment surface commonly is covered by thick mats of Thioploca (sulfur oxidizing bacteria), suggesting that the bacterial mats also may play direct and/or indirect roles in OC and metal concentration, accumulation, and preservation. Q-mode factor analyses of major- and trace-element concentrations in surface sediment samples delineate three dominant element associations: (1) an organic association (OC, Mo, Cd, V. Ni, Cu, and Zn); (2) a phosphate association (Ca, P, Sr, U, Y); and (3) a clastic association (Al, Mn, Ti, Li, Gga, n, Ba, Nd, Th, and Sc). The clastic association was dominant in the 13.5°S transect, whereas the OC-metal association dominated on the 12°S transect. On both transects, phosphorite (carbonate fluorapatite, CFA) is most abundant on the upper slope between 300-500 m. On the 13.5°S transect, a glauconite element association (Fe, K, and Cr) occurs on the slope below 450 m to at least 1000 m where the surface sediments consist of nearly pure medium-size glauconite sands. No glauconite was found on the 12°S transect.

Sedimentary characteristics of Holocene muds deposited under an intense oxygen-minimum zone (OM) off California were studied in surface-deployed gravity and piston cores collected on the continental slope from the Oregon

border on the north to the Mexican border on the south. Based on geochemical evidence, sediments on the southern California slope overall contain the most abundant H-rich, sapropelic marine organic matter as judged by Rock-Eval pyrolysis, OC content, and carbon isotopes. The southern California margin sediments also have the highest overall concentrations of phosphorus (P/Al ratio), CaC03, and Barium (Ba/Al). This suggests that today productivity is greatest on the southern California margin. Concentrations of biogenic silica also are highest in surface sediments off northern California, suggesting that diatom productivity is highest there. The high carbonate productivity on the southern California margin appears to be a continuation of conditions established during late glacial times. The phosphate concentration in sediments on the California margin, as measured by the P/Al ratio, is 100 to 1000 times less than that in sediments on the Peru margin, which is why phosphate deposits are forming on the Peru margin and not on the California margin.

The Instrumental Record of Climate Variability in the Pacific Northwest: Laying the Foundations for an Integrated Assessment of Climate Impacts

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As one of the foundations for the "Integrated Assessment of the Dynamics of Climate Variability, Impacts, and Policy Response Strategies in the Pacific Northwest" project, we have assembled historical records of the marine and terrestrial environment in the Pacific Northwest region. Our longest continuous time series extends back to the late 19th century.

Our goals include objectively identifying spatially coherent climate variability at seasonal, interannual, and interdecadal time scales. Ultimately, we hope to quantify the potential for climate predictability at the aforementioned range of time scales. Preliminary results suggest that there are strong decadal and interannual oscillations in Pacific Northwest climate that are well captured by snowpack, wintertime air temperature, streamflow, and sea surface temperature in Puget Sound and along the coast of Washington State and British Columbia. As noted in previous studies, teleconnections to the El Niño/Southern Oscillation are evident in Pacific Northwest climate records, though less directly than is commonly stated. Nonetheless, teleconnections to ENSOs yield a promising mechanism for making seasonal to interannual climate predictions for the Pacific Northwest region. We are also encouraged by the potential for decadal-scale predictability associated with the longer-time-scale oscillations of the North Pacific climate system. Many of our best climate records were obtained via the PACLIM data base, and we strongly encourage participants in this workshop to maintain and update these valuable climate records.

Uranium/Calcium Variations in the Reef Coral *Porites lobata*

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There are several proxy techniques available to reconstruct SST from coral aragonite such as δ18O and Sr/Ca. Recent studies have shown that the ratio of U/Ca in coral aragonite varies in conjunction with δ18O, Sr/Ca, and the SST of

the water. The purpose of this study is to test the robustness of the U/Ca tracer from several different areas in the Pacific and under varying local conditions. Porites lobata corals were collected in Fiji and Hawaii from "open ocean" sites and sites influenced by stream runoff. Although the Fijian corals are young (~5 years old), the cores collected from Hawaii are from large coral heads that appear to encompass 100 years of continuous growth.

Two of the corals from Fiji were analyzed for U/Ca by isotope dilution ICP-MS and compared to δ18O and the IGOSS NMC weekly SST dataset. At the open-ocean site, the U/Ca and δ18O appear to change in phase with SST. The U/Ca measurements for the site range from 0.85 to 1.25 μmol U/mol Ca; the δ18O ranges from –4.5 to –5.5‰; and the temperature ranges from 26 to 30°C. The inshore site shows more variation in the magnitude of the δ18O signal (–3.8 to –5.1‰) than does the open ocean site and does not always correlate with the instrumental record. Preliminary U/Ca measurements from the two sites in Hawaii range from 0.8 to 1.3 μmol U/mol Ca, which is consistent with measurements made by other workers. Analysis of a 15-year time series of U/Ca from the two Hawaiian sites will be presented.

Correlation of Laminated Late Pleistocene Sediments from the Open Continental Slope Off Central California

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Eighteen out of 46 deep-sea cores recently collected in water depths between 500 and 1000 m along the central California continental margin contain subbottom intervals of laminated sediment. Correlations with 9 AMS 14C-dated cores in the area indicate the laminated sequences occur during three intervals; late Pleistocene Oxygen-Isotope Stage 3 (OIS-3) at about 35 to 40 ka, OIS-2 at about 25, and 15 ka. The similarities of the central California laminations in appearance, composition, and age with varves found off northern California (Gardner and Hemphill-Haley, 1986; Hemphill-Haley and Gardner, 1994; Anderson et al., 1987; 1989) suggest that the central California laminations are also varves. Varve-preserving conditions prevailed at four different times during the last 40 ka along the California margin. The oldest intervals occurred at about 39 ka and roughly coincide with the timing of Dansgaard-Oeschger cycle 12 (DO-12) and Heinrich Event HE-4. The next interval of varves occurred at about 36 ka, coinciding with DO-8 and HE-3, followed at about 25 ka (AMS 14C dated) by similar conditions that coincide with DO-4 and He-2. The youngest varve-preserving conditions occurred at about 15 ka (AMS 14C dated) and coincide with HE-1. During these times of varve-preserving conditions, the oxygen-minimum zone must have been depleted in dissolved oxygen to the degree that precluded benthic bioturbation. This condition could be met either with the dissolved oxygen content of Pacific Intermediate Water being much lower than today, with coastal upwelling being much more intense than occurs today, or both. Our data suggest both mechanisms contributed to the low values of bottom-water dissolved oxygen during the varve-preserving conditions. We speculate that atmospheric changes in the North Atlantic during Heinrich Events were teleconnected to the North Pacific and altered atmospheric and oceanographic conditions there.

Digital image-processing techniques were used to display 8-bit gray-scale profiles of each varve sequence in order to correlate them to one another. Three OIS-2 sequences can be correlated down to individual hemicycles (light or dark layer). Two OIS-3 sequences can similarly be correlated. Individual varve hemicycle thicknesses were compiled to investigate a possible El Niño signal, reasoning that a typical El Niño generates heavy winter rainfall (thick dark layer) along the central California coast and a major reduction in spring and summer upwelling (thin light layer). The thickness (or thinness) of each seasonal laminae should be a reflection of the "strength" of each of these seasonal processes. Spectral analyses of the varve thicknesses did not reveal a consistent El Niño periodicity of 3 to 7 years. In fact, a periodic pattern has been found in only one core so far. This preliminary result suggests that the El Niño/Southern Oscillation may be a rather recent condition, at least in its effect along the central California margin.

The highest correlation occurs between dark-laminae thickness and light-laminae thickness. This correlation suggests that heavy winter rainfall and intense spring upwelling were the most common seasonal climates during those times that marine varves were preserved. However, heavy winter rainfall followed by intense spring upwelling is not a common seasonal succession in today's climate patterns along the U.S. west coast. Today's El Niño conditions typically have heavy winter rainfall followed by weak spring upwelling (thick-dark laminae and thin-light laminae) whereas today's La Niña conditions typically have relatively light winter rainfall followed by relatively intense upwelling (thin dark laminae and thick light laminae).

Potential Insolation Maps of the H.J. Andrews Experimental Forest

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Potential clear-sky radiation receipt is modeled for the slopes of the H.J. Andrews Experimental Forest Long-Term Ecological Research site in the foothills of southern Cascade mountains of central Oregon. The modeling method developed by Williams is selected and applied to the forest area for the times of the solstices and equinox as well as mid-month times in January, February, April, and May to completely characterize the seasonal change of potential radiation of the location. The method uses an 82×111 point grid with a 120 m spacing interval. Resulting maps reveal areas of the forest with extremely steep gradients of potential radiation. These steep gradients have higher absolute values in summer compared to winter. The south-facing slopes which have the highest potential radiation values tend to be at the highest elevations. There are places that receive no direct radiation as far into the year as February. Standard deviation values of potential radiation across the Andrews show the maximum spatial variability to occur in February. There is a decrease in the ratio of diffuse to direct plus diffuse potential radiation from 0.66 at December 22 to 0.23 at June 21. It seems that Lookout Creek approximately divides the Andrews Forest into an area of relatively high potential radiation to the north of the creek and relatively lower potential radiation values to the south of the creek. Potential radiation values seem to be associated with the Andrews GIS data layers of debris flows and predominant tree species zones.

Calibration of a Climate Model for Northwestern Mexico

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We have extended an existing statistically-based climate model of the western United States to provide solutions for northwestern Mexico. Daily date for the 11 northernmost states of Mexico were obtained from national archives in Mexico City and supplied to us through the courtesy of Julio Betancourt (USGS). Maximum temperature, minimum temperature, and precipitation from over 1839 stations are included. Stations with continuous records from 1961 to 1985 were chosen (giving a total of 416) and the 2552 stations with the highest percentages of reporting days were subset for use in calibrating a modified version of the local climate model of Stamm and Gettleman (1995), which predicts monthly maximum temperature and monthly average precipitation from a suite of 22 independent variables.

This version of the LCM did not include two of the original independent variables, and added new ones. Also, both the arithmetic mean value and standard deviation were predicted for five variables: monthly maximum temperature, monthly minimum temperature, monthly temperature range, monthly total precipitation and monthly log (total precipitation).

Independent and dependent variable sets are related through a multiple linear regression analysis. The strength of the relationship for each dependent variable is assessed by use of a multiple correlation coefficient (R2). Both mean monthly maximum temperature and mean monthly minimum temperature have high R2 values, with that of the minimum temperature being slightly higher. Range of temperature is not as easy to predict. Transforming precipitation degraded the strengths of relationship rather than improving it. Mean values are more precisely predicted than standard deviation. Of the standard deviation, that of precipitation is most precisely predicted.

Addendum: Paleoclimate and the Solar Insolation/Tidal Resonance Climate Model

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In climate research instrumental observations of the past 100 years drive speculation on climatic process and global changes in atmospheric circulation. Likewise in paleoclimate research, less precise but much longer time series provide the basis for speculation on ultimate cause(s) and the resulting temporal and spatial patterns of longer term climate change. Recent papers (Karlstrom 1995, 1996) provide detailed analyses of more than 40 high-resolution time series culled from the extensive paleoclimate literature that appear to define cyclical elements of the Solar Insolation/Tidal Resonance Climate Model (Karlstrom 1961 cf.). This paper provides comparable analyses of an additional 20, evidently supportive, climate time series. These tree-ring, historic, pollen, and pluviochronostratigraphic records range in length from 400- to 65,000-years, and spatially from Alaska to Tierra del Fuego, and include both Old World and New World sites. The temporally-defined cycles rang in wavelength from

decades to tens of thousands of years. The presented evidence seemingly fortified previous conclusions that (1) longer term "Ice Age" changes (presumably modulated by Precessional Insolation) were out-of-phase across the Equator, and (2) the superposed complex pattern of secondary cycles (presumably phased by tidal resonances in the atmosphere) were globally synchronous. Analysis of a bioclimate record suggests that differing seasonal timings of fractional higher frequency cycles may contribute to fluctuational variability in biologic time series. The longest pollen records suggest a terrestrial cycle of about 10,000 years, or comparable to that recently noted in higher resolution marine records. When the accumulated number of supportive records is deemed adequate the correlation of secondary cycles can be appreciably improved (within limits of dating uncertainties) by fine-turning to the theoretical Tidal Model.

Diatom, Silicoflagellate and Radiolarian Fluxes in Santa Barbara Basin, California

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Seasonal fluctuations in the total particle, biogenic opal, diatom, silicoflagellate and radiolarian fluxes were observed in a sediment trap deployed at 540 m in Santa Barbara Basin, California from 12 August 1993 to 11 August 1994. Biogenic opal content varied from about 8.6 to 31.8% of the total mass flux, and CaCO3 content varied between 5.6 and 57.9%. Diatoms were the main contributor to the opal fraction (mean daily flux of ca. 4.35 × 105 valves m-2d-1) followed by radiolarians (ca. 6.3 × 103 skeletons m-2d-1) and silicoflagellates (ca. 1.3 x 103 skeletons m-2d-1). The biogenic particle composition of the opaline fraction reflected the hydrology patterns of the area with a combination of California Current and California Countercurrent water masses. Diatoms yielded three flux maxima in February, April-May and June 1994. Species composition associated with the flux peaks differed, probably reflecting different sources. Bacteriastrum furcatum, resting spores of Chaetoceros radicans and a composite of C. concavicornis, and resting spores of C. radicans and C. vanheurckii dominated the diatom assemblages, respectively. In total, 142 diatom taxa were identified. Diatom diversity was lowest during times of highest fluxes. Silicoflagellates peaked in December 1993 with Dictyocha fibula as the main contributor.

Total radiolarian flux peaked in October 1993 and during the diatom peak of February 1994. Warm, surface dwelling fauna from the west and/or south contribute most to the October peak. Fauna of less certain origin constitute the February peak. Relative abundance of warm fauna was high beginning in Augusts 1993 peaking in December, and tapering off for the duration of the time series. Conversely, the percentage of deep-living intermediate radiolarians initially was low and increased with time, peaking in May and June 1994. Radiolarian diversity closely resembles total radiolarian flux with high flux and diversity coinciding, in contrast to the diatoms.

Long-Term Changes in Phytoplankton Chlorophyll *a* Concentration and Community Compositon and Their Relationship to Climate

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The years after 1977 were characterized by low phytoplankton chlorophyll *a* concentrations and a shift in phytoplankton community composition in the upper San Francisco Bay estuary. The long-term changes reflected interannual variation that was associated with changes in water year type. Water year types are associated with changes in the ENSO climatic signal and patterns of change were consistent with the increase in the frequency and intensity of ENSO events after 1977. For climate to be the driving force for changes in phytoplankton, it must affect mechanisms that control phytoplankton biomass and community composition. The influence of climate on environmental factors was examined using 19 years of physical, chemical, and phytoplankton data collected monthly at 16 stations throughout the estuary. Covariance analysis was used to extract the environmental variation associated with the ENSO climatic signal, and this variation was summarized using principal component analysis. Correlations between the principal component axes and phytoplankton community composition and chlorophyll a concentration suggest mechanisms by which climate contributes to long-term changes in phytoplankton communities.

Temporal and Spatial Variability of Streamflow in California During the Past 100 Years: An Indicator of Jet Stream Shift and Moisture Source Change

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We have analyzed streamflow variations recorded at 15 USGS gaging stations in California during the past 90 years or so. The anomalies (departures from the 1960-1990 mean discharge) of streamflow on annual-to-decadal time scales are strongly correlated with precipitation anomalies in each drainage basin. The temporal variations of the 5-year running averages of these records clearly show high/low runoff cycles with a frequency of about 113 years, representing a decadal climate (precipitation) variability. high runoff periods (wet climate) centered around 1982, 1969, 1956, 1940, and 1915. Low runoff periods (dry climate) centered around 1989, 1976, 1962, 1946, and 1932. In addition, the intensity of streamflow during the high runoff periods reveal different spatial patterns. For example, runoff around 1956 was much stronger at the northern California stations than at the southern California stations. In 1993, all stations (four) in southern California showed very high runoff while the other stations showed weakly increased runoff. Although the causes of the decadal climate (precipitation) variability are presently now known with certainty, the use of streamflow records may help us understand the relative strength of moisture sources and shift of the jet stream in atmospheric circulation. Precipitation regimes in California are influenced by three moisture sources: northwesterly flow (polar front) related to the Pacific/North America anomaly, southwesterly flow controlled by the tropic ENSO pattern, and southeasterly flow governed by the summer monsoon. A preliminary assessment shows that variations of California runoff on decadal time scale, but not on annual time scale, are strongly correlated with ENSOs. This implies that the northwesterly flow may be blocked by the subtropical high-pressure system with descending, dry air in

mid-latitude zones when the Southern Oscillation is strong, causing drought in California. When the Southern Oscillation is weak, the northwesterly flow can penetrate farther south and the El Niño event can bring more precipitation from the equatorial Pacific to California. Summer monsoon mainly affects the climate and streamflow in southern California. Strong runoff in 1969 and 1993 recorded by gaging stations in the south may indicate the strengthening of the summer monsoon.

Late Glacial Millennial Scale Hydrological Events in Western Great Basin, California and Nevada

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The timing of the last major pluvial event and of six distinct desiccation events in Great Basin during late glacial to deglacial period has been investigated through 14C and U-Th age determinations and 14C age determinations. U-Th isochron ages of tufas formed on shorelines suggest that the last pluvial event was synchronous in Lake Lahontan and Searles Lake at about 16,500 calendar years B.P (i.e. between 13,500 and 14,000 radiocarbon years B.P.). Radiocarbon measurements on subvarnish organic matter are consistent with an age of 14,000 radiocarbon years, suggesting that this pluvial event was possibly linked with Heinrich Event #1, the last of a series of major iceberg discharges into the North Atlantic Ocean. The U-Th age determination on six evaporite samples within seven mud-salt interbedded layers in Searles Lake (Lower Salt Unit) suggests close correlation of the millennial-scale climates recorded in Greenland ice cores (Dansgaard-Oeschger events) and Searles Lake between 23,000 years and 35,000 calendar years BP.

Hydrological conditions in the Searles Lake drainage basin appear to have responded to the climate forcing responsible for the millennial-scale climate fluctuations in northern polar region during late glacial time. Dust events in Greenland and hydrological anomalies in the Great Basin point to dramatic changes in zonal atmospheric circulation and to more efficient moisture transport from the tropics to mid-latitudes during each cold phase of the Dansgaard-Oeschger cycles. Geographical distribution of the areas impacted by the last of these events bears a resemblance to that for ENSO-related precipitation anomalies.

Uncommonly Cold Half-Decade in the Colorado Front Range

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Niwot Ridge is located in the Front Range of Colorado, just to the west of the Denver/Boulder metropolitan area. The instrumented records of over four decades, from two of these sites, C1 at 3300 m and D1 at 3749 m, show an uncommonly cold period beginning in 1981 and continuing through 1985. the cold period is more pronounced at D1, where the average annual temperature is 2.5°C colder than the 44-year annual average.

This cooling is particularly interesting because it occurs without similar cooling just 27 km to the east, and it occurs during a period of general warming in North America. Therefore, in an effort to understand the process(es) causing this cooling, other parameters such as solar radiation, precipitation, and pressure grid anomalies, as well as the temporal and spatial distribution of the colder temperatures, are examined.

A Comparison of the Paleosecular Variation Record from Late Pleistocene Lake Estancia with Other Records from Western North America

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A detailed record of paleosecular variation of the geomagnetic field has been constructed from sediments of latest Pleistocene Lake Estancia. The record reveals millennial-scale paleosecular variation broadly consistent with observations in other contemporaneous records from western North America. This record also contains prominent submillenial-scale variations. Strong agreement among several paleosecular variation curves from western North Americas indicates that these records may be useful for the correlation of sedimentary sequences throughout a large region. The Estancia record, tied to an accurate geochronology, contributes to the construction of a high-fidelity "master curve" for western North America. It is hoped that future records of paleosecular variation may "tie into" this master curve with minimal absolute age dating.

Tempus Fugit! PACLIM Data Sets Need Update

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The AGU Geophysical Monograph Volume 55 was a timely and valued product that justified PACLIM's very existence. Looking into the patterns and trends of those, and other time series, questions abound. Where are we now? What has the recent decade's notable variability done to presumed trends in these, now fore-shortened, records? Keeping pace with the extreme weather events of the recent fifteen years has been hectic, and a sure change from the previous few decades' relative monotony. With the broad spectrum of agency and institutional science interests pitching for ever more limited funds, the glitzy doomsday climate warming scenarios appear to have won the day. Is the fundamental message wrong? Would warming be bad? Would cooling be worse? History tells the tale. I would be loath to stop anything that would sustain a general global warming, within reason. Historically, humans thrive during warm, wet periods and suffer tremendous problems during cool, dry epochs-particularly when these are punctuated by warm, wet years with pestilence and disease having created havoc within debilitated societies. The 19976 climate shift and related ecosystem changes over great sections of the globe have begun clear signs of reversal. The Pacific sardine has come and gone again, anchoveta and an array of Peruvian fauna that were prevalent in the 1950s and 1960s are back, and under intense exploitation, once again. The Gulf of Alaska has also warmed and cooled. Perhaps more than ever, the messages from PACLIM need to be brought to the public. Are there any prognostic symptoms in the scope? If so, where?

Opportunities to reflect on the observational basis of most of the climate predictions and trends still come up short of answers, primarily due to inconsistencies between the records, and questions about the presumed causes and effects. It is time for PACLIM participants to readdress their data sets, and bring them up to date.

Response of Whitebark Pine Krummholz Leader Release to 20th Century Climate Change in the Sierra Nevada, California

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Treeline can often sensitively reflect short-term changes in climate. We are particularly interested in whitebark pink (Pinus albicaulis) because (1) it is an important tree in the subalpine forests of the Sierra Nevada, and (2) it changes growth form from shrub-like krummholz to upright tree in response to environmental change. At its elevational limits, conditions such as heavy snowpack and icy winds prevent the whitebark pine krummholz from growing above the snowpack. However, given milder conditions, a krummholz will send up one or more vertical stems or leaders. We use cross sections of krummholz leaders at the point were the stem emerges from the top of the krummholz canopy to determine the calendar year in which vertical release occurred. We compare the dates of release to the 20th century climate data from records at Yosemite Valley and Tuolumne Meadows. We find a sharp increase in the number of stem releases during the late 1940s and early 1950s. This corresponds to a steady increase in average June through August temperature seen in the climate record. keyword: dendrochronology, treeline, krummholz

A Model Linking Climate to Growth and Dispersal of Saguaro

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Saguaro (Carnegia gigantea) is the defining species of the Sonoran Desert, a species whose distribution has changed dramatically during the Holocene and which may be sensitive to future climate change including that associated with a greenhouse effect. To evaluate potential changes in Saguaro distribution, we have developed (in cooperation with the USGS Desert Laboratory) a simulation model that uses high-resolution Monte Carlo solutions of climate and a set of rules for saguaro survival, growth, dispersal, establishment, and mortality. We base our climate solutions on a modified version of the Local Climate model of Stamm and Gettleman (1995) which has been supplemented by calculation of standard deviations as the standard error of the prediction from the regression equations and is solved at a grid resolution of 15 km throughout the Sonoran Desert, including the states of Arizona, Sinaloa, and Sonora.

Using the recently published Plant Atlas of the Sonoran Desert (Turner, et al., 1995) we have identified grid cells in which saguaro are known to occur and extracted LCM solutions of temperature and precipitation for each month at those points. Ranking these, we classify the suitability of the climate in all grid cells according to the calculated 6 and 0 percentile values. Growth rate depends on height and climate state. Precipitation exceeding the 6 percentile range leads

to growth at a slower rate and if precipitation is less than the 0 percentile value, no growth occurs. Height of an exemplar plant in each cell is incremented annually and a height of 2 meters signals dispersal of seeds to adjacent cells. Successful completion of the seedling state (at 100 mm height) requires all months in the 10-year period following germination to lie within the 6% to 94% climate bounds. Random mortality occurs at a height-dependent rate (Pierson, 1995, personal communication).

The model illustrates several phenomena consistent with field observations: (1) elevation-dependent survival, growth, and spreading; (2) geographically varying growth and spreading rates, higher in the more humid east, and (3) spreading from established locations at rates consistent with paleoclimate data. Simulations extending for hundreds of years of stable climate show the dynamic nature of the population.

Pandora Moth Outbreaks in Central Oregon: A Dendrochronological Study

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Pandora moth is a frequent defoliator of ponderosa pine in the forests of central Oregon; however, there have been no long-term studies of this insect and its effects on the forest ecosystem. We used dendrochronological techniques to examine timing and intensity of the defoliation through its effect on radial growth. Historical records document the occurrence of past defoliation events in 1893 (Carolin 1968) and 1920-25 (Keen 1937) that show up clearly in the host trees as periods of reduced growth. These reduced growth signatures are a proxy for past defoliation events. We identified 17 episodes of reduced growth over the past 500 years in a site collected in the Deschuttes National Forest.

Monte Carlo Simulation of Streamflow of the Salt River, Arizona

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Water resources evaluations for climate change scenarios (such as a greenhouse effect) need to represent both the expected change and the uncertainty in that change. Since water resources such as streamflow and reservoir levels depend on a variety of factors each subject to significant uncertainty, it is desirable to formulate methods of representing that uncertainty in the forcing factors and from this determine the uncertainty in the response variable. We report here progress in the representation of the uncertainty in climate input upon the uncertainty in the resulting estimated hydrologic response. Our simulations are the first to link a stochastic Local Climate Model that is a modified version of that reported by Stamm and Gettleman (1995) and a Snow and Surface Hydrology model based on that of Orndorff (1994). For illustration, we use a 5 km × 5 km grid over an area of 30,805 km2 which contains the drainage of the Salt River, Arizona. This river forms a critical water supply for the greater Phoenix area, and the utility of the water supply is dependent upon wintertime snowfall and timing of snowmelt.

The results of the LCM are monthly mean maximum daily temperature (TMAX) and total monthly precipitation (PREC). We also derive standard deviations for

TMAX and log (LPREC) as the standard error of the regression of the canonical correlation model. Together they form the spatially-varying parameters of frequency distributions of TMAX (normal) and PREC (lognormal) at each point of a grid. Monte Carlo perturbation of the climate using these parameters provides stochastic input into a mainly deterministic SSHM. Results of the SSHN with this stochastic input are long-term monthly runoff over each grid cell, and discharges for specified drainage which can be compared to observed discharge at the same point.

Comparison of modeled with observed streamflow at Roosevelt Lake shows that mean discharges are very close to the observed values, but the standard deviation of discharge is different. Observed standard deviations are more than an order of magnitude larger than the modeled ones. Analysis of standard deviation of precipitation at 14 stations within the solution domain has shown long-term variations from one 10-year period to another of factors of 2× to 5×. One explanation for the discrepancies in the discharges may be the need to define boundary conditions for solution of the LCM that corresponds to the same time period being tested rather than an average period. Another possible improvement could be to treat standard deviation of TEMP and PREC as further dependent variables in the LCM. We have implemented the second of these two methods.

100 Years of Biogenic Silica Flux to the Santa Barbara Basin and Its Relationship to Climate

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Santa Barbara Basin varved sediment is an invaluable resource for reconstructing the ocean/atmosphere of the northeast Pacific. Although various time scales can be studied, we focus on annual resolution of the past century to establish relationships between the biological record preserved in the sediment and instrumental records of the region. These relationships will ultimately be applied to a longer biological record from the SBB for high-resolution modeling of paleoclimate.

The annual total, warmwater, and deep-living radiolarian accumulations to SBB sediments from 1875-1991 were tabulated from two cores. The resulting time series from the two cores are similar and capture several aspects of climate and circulation of the California Current System. For example, fluxes of total land percent warm radiolarians closely resemble regional low frequency (decadal) SST. Deep-living radiolarians and resting spores of upwelling diatoms, indicative of strong southerly transport in the California Current and upwelling, fluctuate at low frequency and exhibit low relative abundance in the late 1980s-1990, similar to the drop observed by others (Roemmich and McGowan, 1995) in zooplankton within the Southern California Bight. Additionally, we have constructed an index with the warm and deep-living fauna, which reflects seasonal atmospheric circulation over the North Pacific.

Tree-Ring Reconstructions of Winter Climate and Circulation Indices for the Southwestern United States: Climate Extremes and Their Relationship to Circulation Patterns

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The goal of this research is to investigate the influence of atmospheric circulation on winter climate in the southwestern United States. Previous research of this author identified the key circulation features influential to climate for the period of modern climate records. A set of circulation indices was generated that described important circulation features, including the Southern Oscillation Index, a sea surface temperature index from the equatorial Pacific, a modified Pacific North American index, and two indices that feature a southwesterly low pressure center; the Pacific high/southwestern low and Southwestern trough indices. The spatial and temporal relationships between circulation, as described by the indices and climate (precipitation and temperature) were examined.

In the next phase of research, a network of 75 tree-ring chronologies located throughout the Southwest was used to reconstruct regional winter climate for southern California, Arizona, and western New Mexico. The climate variables reconstructed for the winter season (November-March) were: total precipitation, number of rainy days, and average maximum temperature for each of six regions. Regression models explained 42-71% of the variance in the regional climate series. Reconstructed climate series extend from 1702 to 1983.

In the final stage of this research, the network of tree-ring chronologies has been used to reconstruct the circulation indices. The tree-ring chronologies explain variances in the indices ranging from r2adj = 0.26 for the winter sea surface temperature index to r2adj = 0.78 for the Southwestern Trough index. Reconstructed regional climate series and circulation indices were ranked and years of highest and lowest values were compared. Results show that years of climate extremes often coincide with extremes in one or more of the ENSO-related indices (SOI, SST, and/or PNA) and with one or the other of the two southwestern low indices. An examination of the groupings of regions with extreme values in a given year shows that the influence of these circulation features during extreme years is spatially variable. Reconstructed climate and circulation indices both suggest that the 1800s included more dry extremes than the 1700s or 1900s.